A Massively Parallel Algorithm for Real-Time Wavefront Control of a Dense Adaptive Optics System

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SELENE is an adaptive optics system for beaming power through the atmosphere. The real-time control of SELENE poses a formidable computational challenge since it represents an extremely large system, in the neighborhood of N = 250,000 degrees of freedom, with a very fast dynamics, demanding a controller bandwidth of approximately 1KHz. The implementation of a fully coupled optimal controller requires a set of matrix-vector multiplications wherein the matrices are dense with a dimension of $N^2 \times N^2$. This results in a computational complexity of $0(N^4)$ for the optimal controller which implies a computation power on the order of hundreds of Teraflops for its real-time implementation. Such a computational power is far beyond the capability of even future generations of massively parallel architectures.

In an accompanying paper, we present a nearly optimal control strategy whose main computational kernel is the solution of Poisson equation. Using the so called fast Poisson Solvers, the computational complexity of this control strategy is of $O(N^2 LogN)$ which represents a drastic improvement over that of fully coupled optimal controller. However, even with a such an improvement, the real-time implementation of this control strategy still requires a computational power of the order of tens of Gigafolps. This clearly suggests that only an efficient implementation of the algorithm on emerging massively parallel architectures can lead to a satisfactory result.

In this regard, the emerging massively parallel MIMD architectures with their ever increasing power and decreasing cost seem to be natural candidates for implementation of our control algorithm. However, these architectures are most suitable for algorithms with simple communication requirements. The fast Poisson solvers, proposed in the literature, have rather complex communication structures which make their implementation on these architectures inefficient.

In this paper, we present a new algorithm for solution of Poisson equation that is optimal for implementation on massively parallel MIMD architectures. This algorithm not only has a simple communication structure but it also allows the exploitation of concurrency at two computational levels since the computation performed by each processor can be also vectorized. This feature is particularly suitable for MIMD architectures such as Intel Delta and Cray T3D which use processor nodes with a significant vector processing capability.